

Physical Properties and Observables of the Warm/Hot IGM

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1. Approximate Physical Properties of the WHIM
2. Deviations from Equilibrium
3. Which WHIM? The effect of Galactic Winds
4. X-ray Spectroscopy and Absolute Measurements

1. The WHIM: approximate physical properties

Gravitational collapse: shocks heat the diffuse IGM

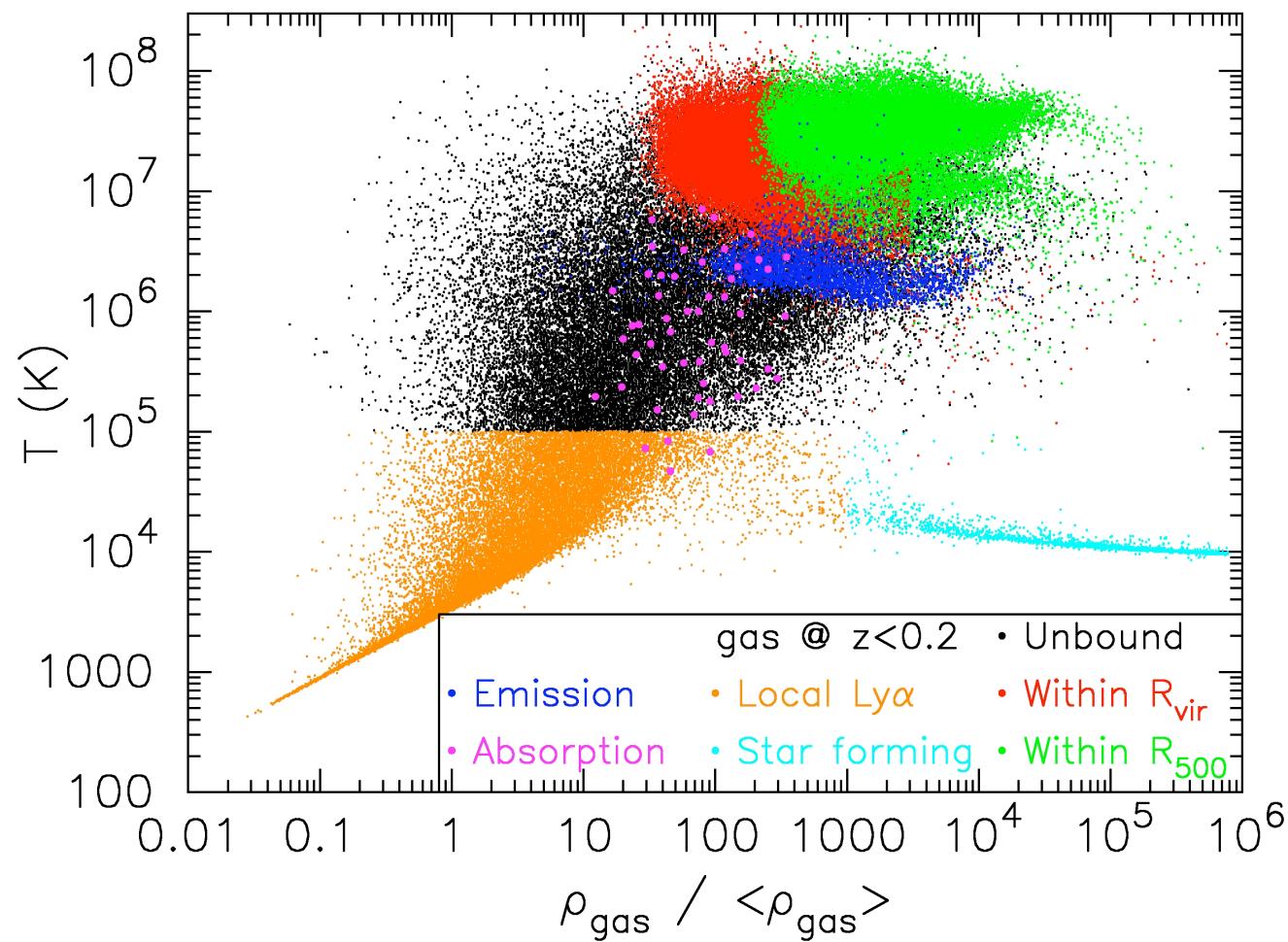
$$\frac{1}{2} m_p (l H_0)^2 = 3/2 kT;$$

$$l = 1 \text{ Mpc}: T = 2 \times 10^5 (l / 1 \text{ Mpc})^2 h_{70}^{-2} \text{ K}$$

Detailed DM/Hydro simulations:

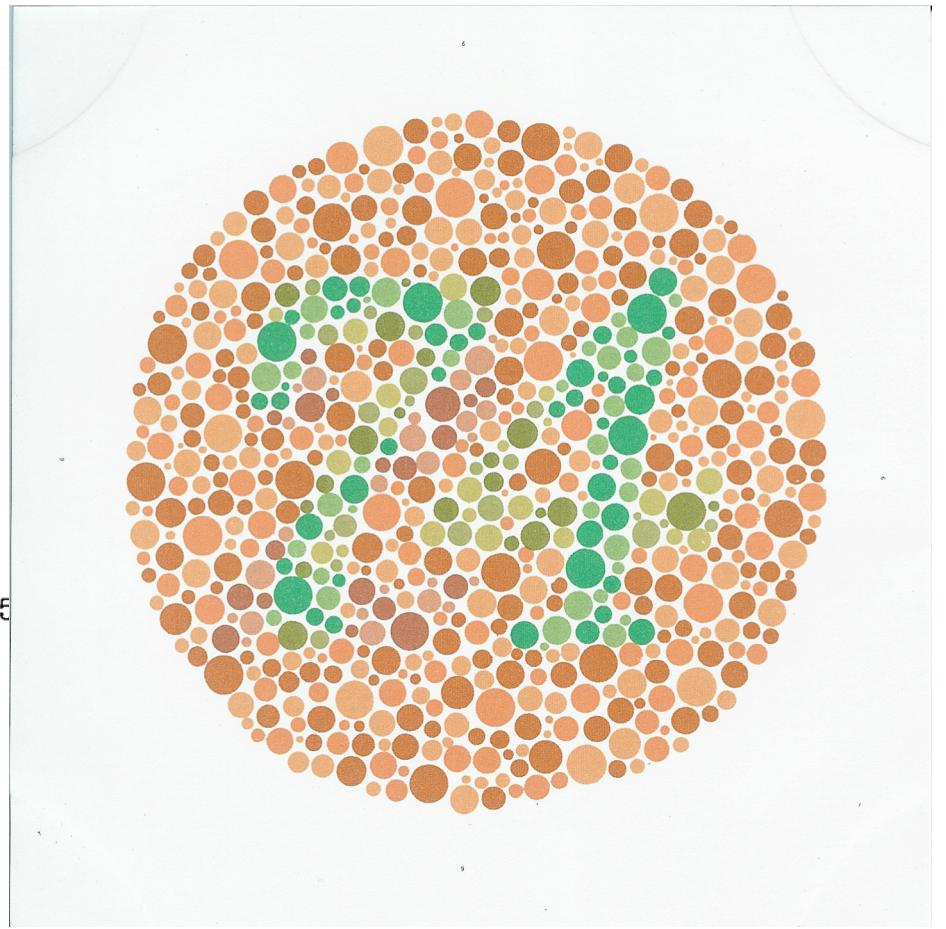
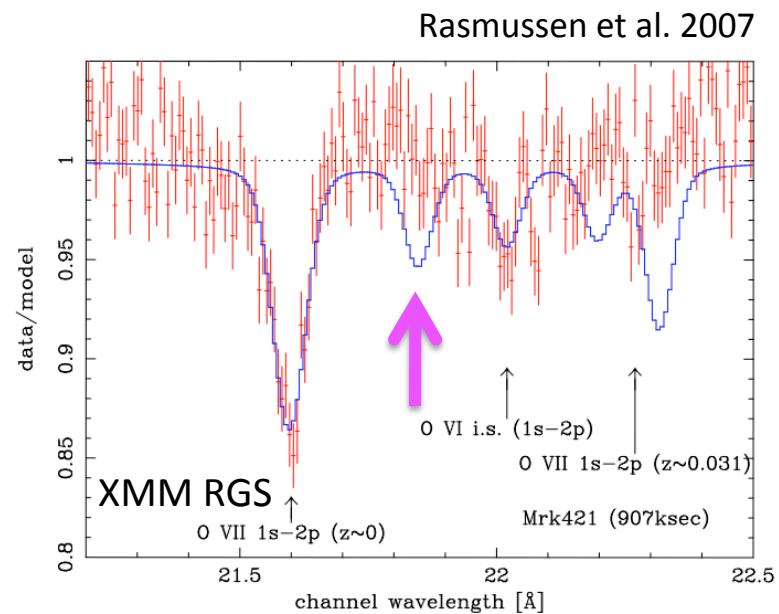
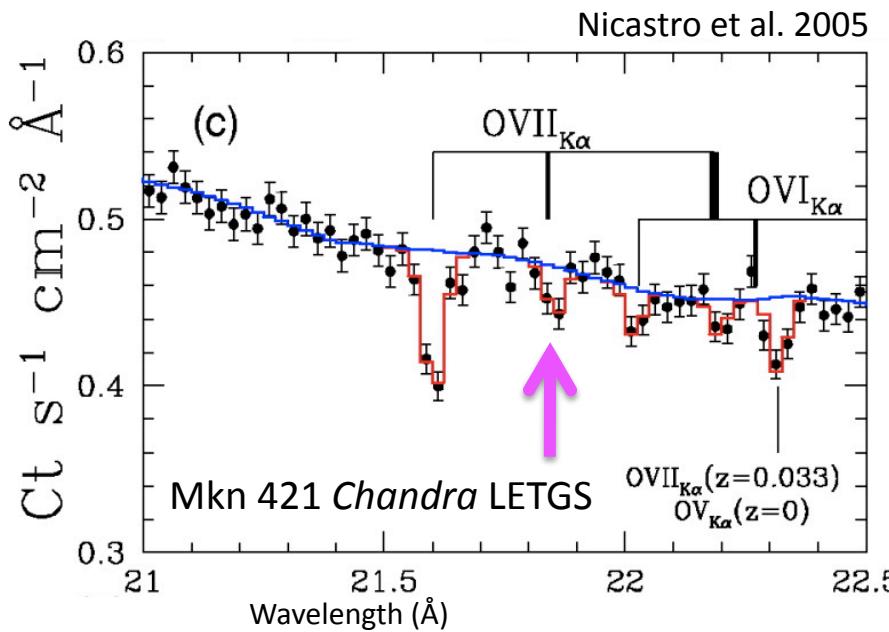
- overdensities $\delta \sim$ few, to few dozen; but with large range in density;
- physical density $\delta \langle n_B \rangle = \delta \cdot 2 \times 10^{-7} \text{ cm}^{-3}$ (!!)
- average T correlates with δ , but with large spread, 10^{5-7} K
- metallicity: ??, from $Z/Z_\odot = 0.01$ (Ly α forest) to 0.3 (clusters); probably strongly density-dependent

May hold up to ~40% of the baryons at z=0



WHIM highly ionized;
 at $z=0$, shocks + X-ray photoionization ionize O up to He- and H-like
 → unique spectroscopic signature in X-ray transitions

Detection?



Scharf et al., 2000 (ROSAT)
 $\delta \sim 100$

(see also Luca Zappacosta, Alexis
 Finoguenov, and Jan Willem den Herder)

2. Deviations from Equilibrium

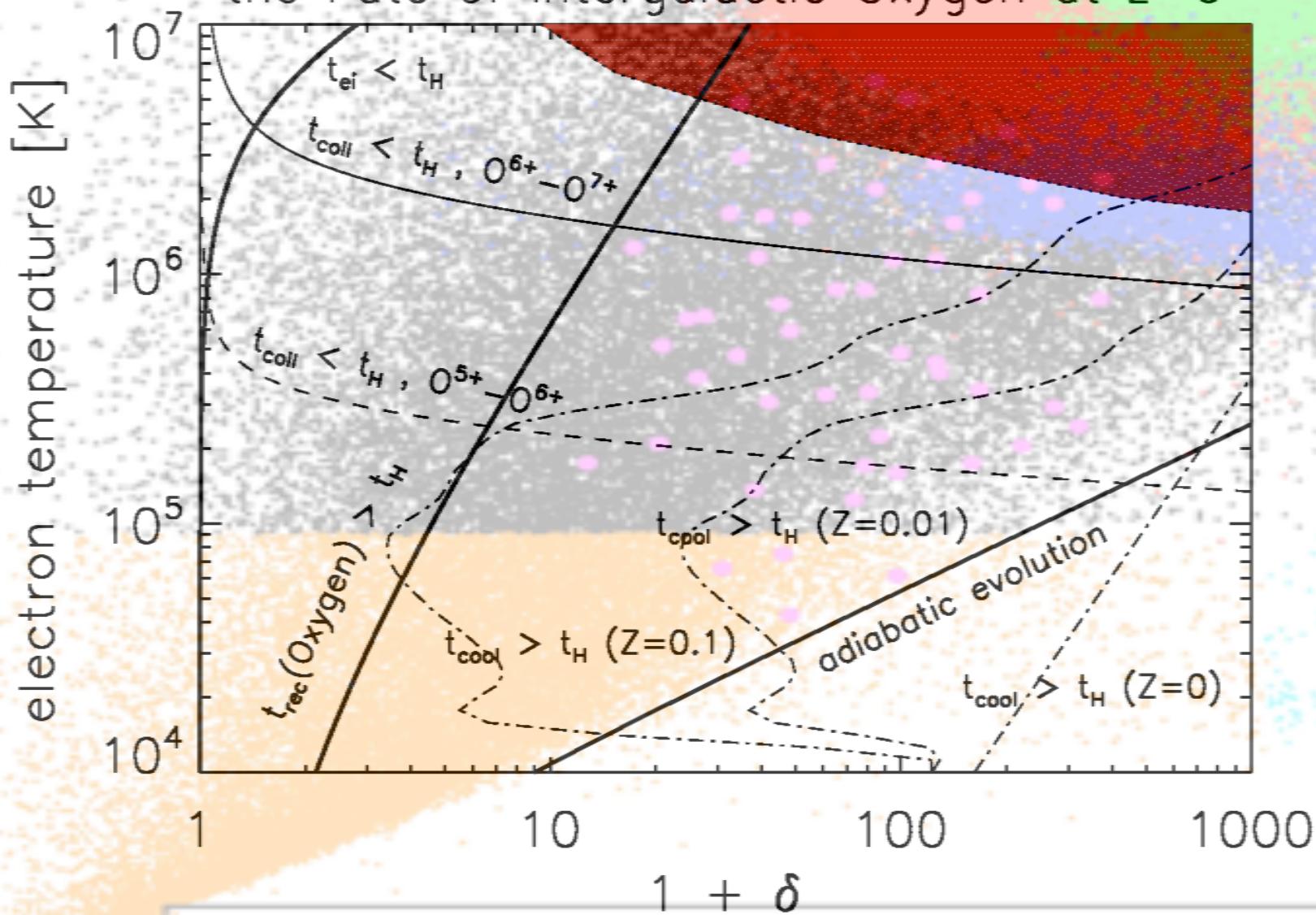
Physical density very low:

many processes out of equilibrium, even over Hubble time

(e-i equilibration, heavy ion ionization equilibrium,
importance of photoionization, radiative cooling, thermal
stability; interesting effects on shock structure? (**B!**);
particle acceleration, effect of nonthermal e^- on ionization
balance and line excitation,)

All of these have effects on spectroscopy of heavy ions!

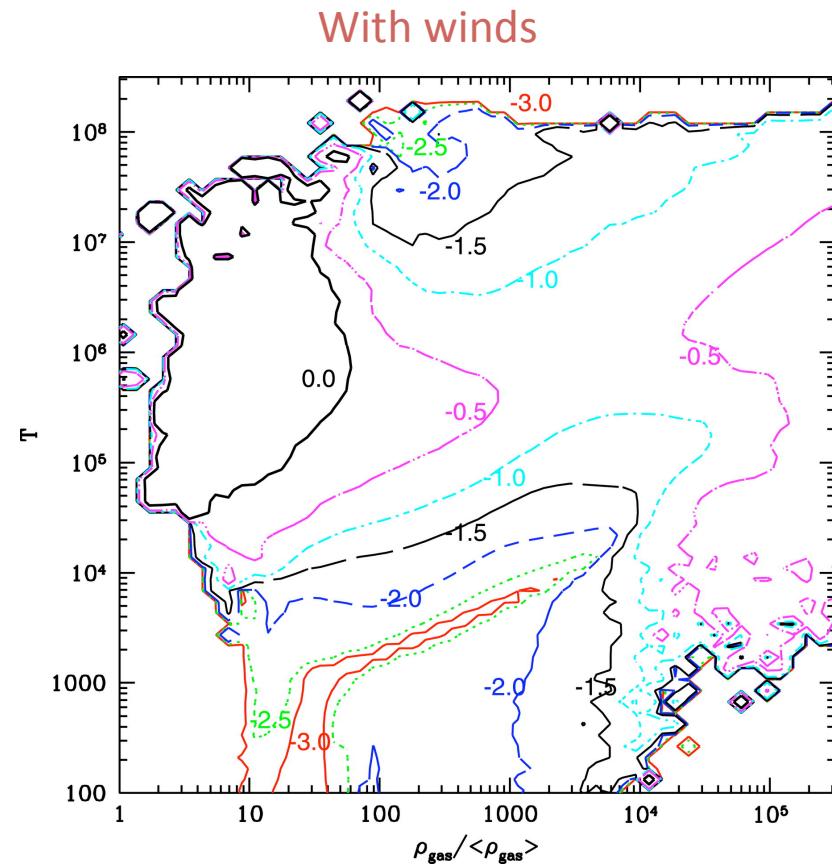
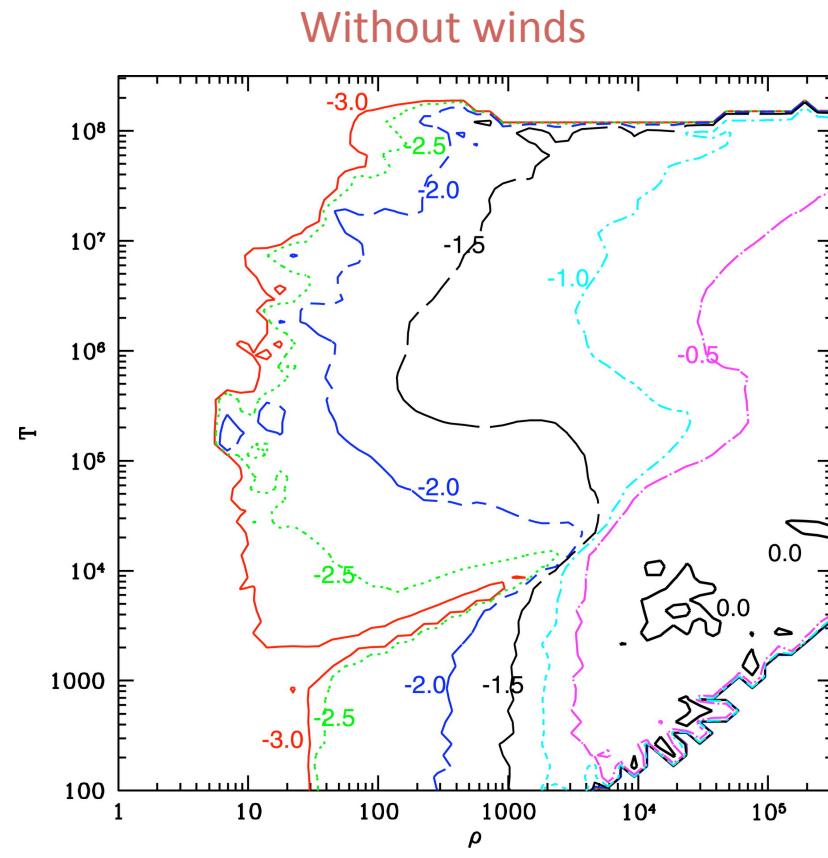
the Fate of Intergalactic Oxygen at $z=0$



gas @ $z < 0.$

- Emission
- Local Ly α

Which WHIM? The effect of Galactic Winds

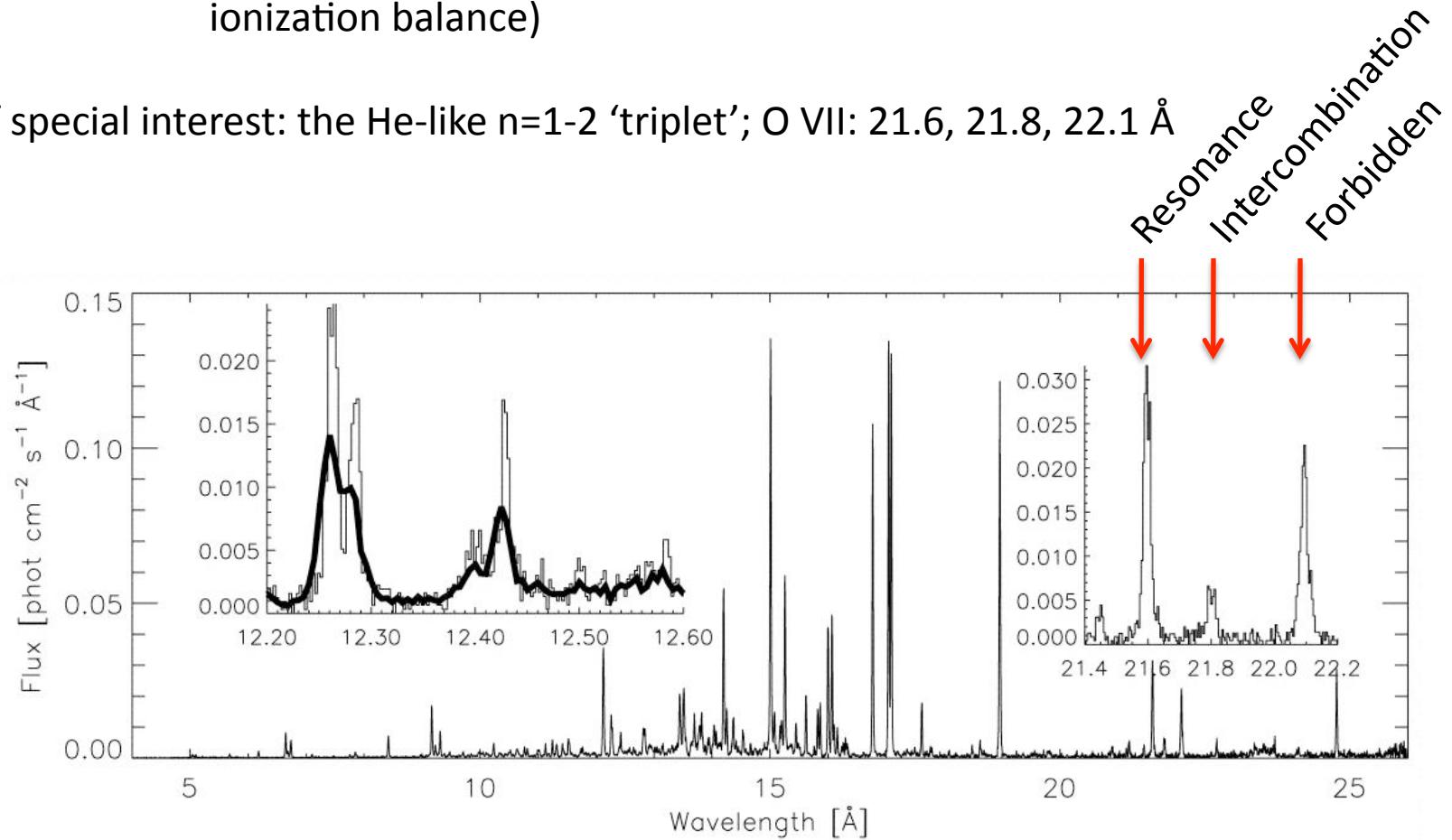


Cen & Ostriker, 2006

X-ray Spectroscopy and Absolute Measurements

Emission line intensity + absorption line EW: $n^2 L, nL \rightarrow n, L$ (for assumed abundance, ionization balance)

Of special interest: the He-like n=1-2 ‘triplet’; O VII: 21.6, 21.8, 22.1 Å



R, I, F line ratio's sensitive to
excitation mech (CX, rec.),
 T_e , ionization non-eq., ...

Capella, *Chandra* HETGS (Canizares et al. 2000)

Absolute Abundances

Churazov et al. (2001):

I (forbidden, intercombination): CX, recombination $\rightarrow A n^2 L$

I (resonance): CX, recombination $\rightarrow A n^2 L$ **PLUS**

resonance scattering of CXB continuum $\rightarrow A nL$

If sources of the CX resolved out: WHIM filaments light up in resonance line!

Emission spectroscopy of O VII triplet equivalent to absorption/emission;

At $\delta = 30$, $T_e = 10^6$ K: scattered/thermal resonance line emission ≈ 2 !

With reasonable assumption for L , get A .

Definite advantage of imaging emission line spectroscopy:

contrast; 3D; estimate absolute densities, abundances

Requirements in terms of spectroscopic resolution: modest ($\Delta E \sim 2$ eV)